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COMPARATIVE STUDY OF ELECTRON-PHONON INTERACTION IN THREE VANAD--ETC(U)
JAN 77 J A WAYNERT, M LEVY

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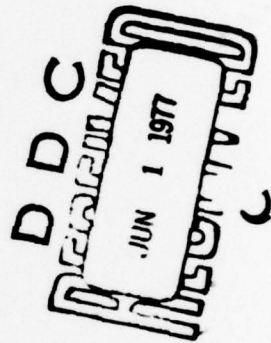
COMPARATIVE STUDY OF ELECTRON-PHONON INTERACTION
IN THREE VANADIUM SAMPLES OF VARYING PURITY*

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S.108 COMPARATIVE STUDY OF ELECTRON-PHONON INTERACTION IN THREE VANADIUM SAMPLES OF VARYING PURITY*.

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Recently a theory for the transport coefficients of pure type II superconductors ($\ell > \xi_0$) near the upper critical field H_{c2} was developed by A. Houghton and K. Maki (HM).¹ The electron-phonon interaction is expected to exhibit two types of behavior: very near H_{c2} , the ultrasonic attenuation should exhibit gapless behavior ($\alpha_n \sim \alpha_s$)/ $\alpha_n \sim H_{c2} - H$; further away from H_{c2} , the absorption should go as $\Delta\alpha/\alpha \sim \sqrt{H_{c2} - H}$. Although this theory has been compared to niobium² where qualitative agreement was found, there has been no definitive study performed on vanadium. The present work relates the results of ultrasonic attenuation measurements as a function of temperature and applied magnetic field in three vanadium samples with resistivity ratios of 8,245, and about 400, hereafter referred to as samples 1, 11, and 111 respectively.

HM have developed a theory for the low frequency response functions for clean type II superconductors when the magnetization M is small. Their expression for the damping factor provides simple analytical forms for both the thermal conductivity and the ultrasonic attenuation in terms of a single dimensionless parameter $u = 2\sqrt{\pi} \Delta^2 \ell / \hbar^2 k_F v_F^2$ for the limit $T = 0$ K. In terms of this parameter, the normalized attenua-

Table I

Sample	Length	Diameter	T_c (a)	T_c (b)	$\Delta(0)/kT_c$	ℓ_1	$\ell_2 (10^{-4} \text{ cm})$	$\frac{\ell}{\xi}$
1	3.9cm	0.6cm	4.81	4.69	$3.5 \pm .1$	0.2	0.4	110
11	3.8cm	0.6cm	5.26	5.26	$3.5 \pm .2$	1.0	2.1	110
111	0.6cm	0.5cm	5.34	5.27	$3.3 \pm .2$	1.4	4.0	100

(a) from extrapolation of H_{c2} data to $H_{c2} = 0$

(b) from attenuation vs temperature data

tion for transverse waves with phonon wave vector \vec{q} parallel to the applied field H is

$(\alpha_n - \alpha_s)/\alpha_n = \Delta\alpha/\alpha = 15\mu[\mu^2(1-\mu^2)J_1 + \pi/16 - \mu/3 - \pi\mu^2/4 + \mu^3]$ where $J_1 = \pi/2 - (2\mu/\sqrt{\mu^2-1}) \tan^{-1}[(\mu-1)/(\mu+1)]^{1/2}$, Δ is the spatially averaged order parameter, k_c is the reciprocal lattice vector of the lattice, v_F is the Fermi velocity, and ℓ is the electron mean free path. Relating these parameters to experimental observables,³ we find

$$\mu = \frac{\ell}{\pi \hbar^2 v_F^2 N(0)} \left[\frac{\phi_0}{2H_{c2}} \right]^{1/2} \left[H_{c2} - \frac{dH_{c2}}{dt} \right] \frac{H_{c2} - H}{1.16[2\kappa_2^2 - 1] + n} \text{ where } \phi_0$$

is the flux quantum, $N(0)$ is the density of states at the Fermi surface, n is the demagnetization factor, and κ_2 is the Maki-Tsuzuki parameter. This expression implies $\mu = f(t) \bullet [H_{c2} - H]$ where $f(t)$ is an experimentally determined function of the reduced temperature $t = T/T_c$.

Figure 1 illustrates the linear relationship between μ and $H_{c2} - H = \Delta H$ at a few temperatures for sample 11, while figure 2 illustrates the resulting fit of the theory to the experimental points at the same temperatures. Note that H_{c2} is also easily obtained at each temperature and its resulting temperature dependence for sample 11 is shown in figure 3. We have intentionally eliminated the data points for extremely small ΔH values in samples 11 and 111 because of a one

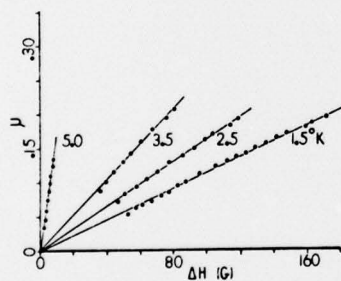


Fig. 1 - $f(t) = \mu/\Delta H$ shown for sample 11.

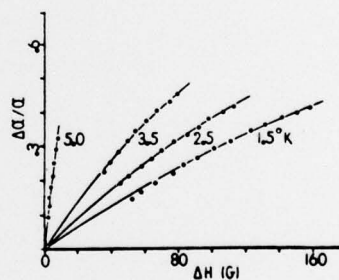


Fig. 2 - \bullet data points, —HM theory for sample 11.

dimensional fluctuation effect⁴ which occurs here in pure samples, causing a rounding in the attenuation. The effect was minimal in sample I and has not been included in the HM theory.

The temperature dependence of ℓ was determined by using Pippard's⁵ result for attenuation in normal metals. His theory shows that the attenuation in the normal state α_n is proportional to $\omega^2\tau$ for $q\ell < 1$ and to ω for $q\ell > 1$ ($\ell = v_F\tau$; $\omega = qv_S$). Having applied a magnetic field sufficient to turn the sample normal, and having varied the temperature from 1.5° to T_C , we found the attenuation constant in all three samples. Since doubling the applied field also had no effect we assumed that the electron mean free path in the normal state was independent of temperature and magnetic field in the region of interest. Finnemore⁶ has experimentally found that for "not too pure" samples, $K_2(t)/K_2(1)$ obeys the same temperature dependence for a wide range of sample purities. Using this fact and the data of Sekula and Kernohan⁷ and the relation $K_2(1) = K = K_0 + 7.53 \times 10^{-3} \rho_0 \gamma^{\frac{1}{2}}$ we were able to determine $K_2(t)$ for all three samples.

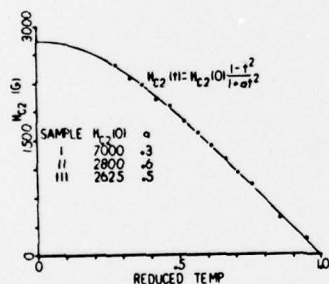


Fig. 3 - H_{C2} as function of t for sample 11.

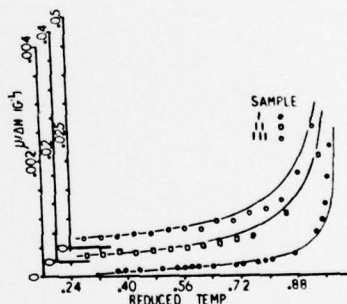


Fig. 4 - $f(t)$ vs t for each sample. Same t scale for each curve. Sample I, 45MHz; II, 15MHz; III, 255MHz; all transverse waves $\vec{q} \parallel H$.

The final result is an independent determination of $f(t) = \mu/\Delta H$ which can be compared to the discrete values obtained above. The agreement can be seen in figure 4. In these plots, the mean free path is used as a fitting parameter to the experimental point at the lowest temperature. This value (ℓ_1) can be found for each sample in table 1.

In sample 111 we were able to obtain frequencies high enough to manifest the transition region between $q\ell < 1$ and $q\ell > 1$ for normal metals as described by Pippard (see fig. 5).⁵ This allowed an independent determination of ℓ and by comparison of residual resistance data, similar values were obtained for samples 1 and 11 (labeled ℓ_2 in table 1). As is evident from figure 4 and table 1 there is reasonable agreement between our experimental results and the HM theory.

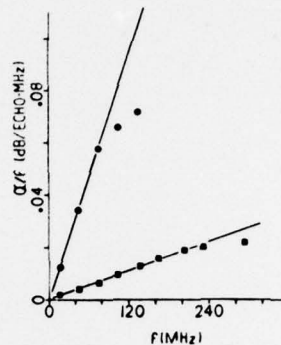


Fig. 5 - Attenuation exhibits onset of $q\ell > 1$ regime.

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- *Research supported by AFOSR Grant No. 71-2079.
- 1. A. Houghton and K. Maki, Phys. Rev. B4, 843 (1971).
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The ultrasonic attenuation coefficient has been measured in the mixed state of three samples of single crystal vanadium of varying purity in order to determine the effect of impurities on the electron phonon interaction in the mixed state of vanadium. The resistivity ratio of the three samples was 8, 245, and 400. Within experimental error the superconducting energy gap of the three samples was 3.5 kT _c . The electron mean free path determined ultrasonical- ly was 0.4, 2.1 and 4.0×10^{-4} cm. respectively. A recent theory is presented		

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phonon wave vector
order parameter
reciprocal lattice vector
Fermi velocity
electron mean free path
flux quantum
density of states
demagnetization factor
one dimensional fluctuation
normal metal
residual resistance

cont 20. Abstract - continued

→ which indicates that electron phonon interaction is a strong function of the electron mean free path in the mixed state. The relative attenuation decreases more rapidly for the purer samples as the magnetic field is decreased from the upper critical field and therefore the electron phonon interaction term also decreases more rapidly. There appears to be good quantitative agreement between the experimental results and the theoretical predictions.

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